A HABITAT MAP AND UPDATED HIGH WATER BOUNDARY OF THE MUSQUASH ESTUARY

M.E. Greenlaw, M.N. Schumacher, Q.M. McCurdy

Science Branch, Maritime Region
Fisheries and Oceans Canada
Biological Station
531 Brandy Cove Road, St. Andrews, NB
E5B 2L9

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Fisheries and Oceans Canada
St. Andrews Biological Station
531 Brandy Cove Road
St. Andrews, New Brunswick
E5B 2L9

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ABSTRACT

Greenlaw, M.E., Schumacher, M.N., McCurdy, Q.M. 2014. A Habitat map and updated mean high water boundary of the Musquash Estuary. Can. Tech. Rep. Fish. Aquat. Sci. 3093: iv + 26p.

This document describes the creation of a habitat map for Musquash Estuary, providing the total area and location of each of nine distinct habitat types within the Estuary. As a result of this project, a tidally-based delineation of the mean high water boundary of the AIA and intertidal were also created. With LiDAR data, a precise mean high water level could be delineated to improve the measurement of habitat types in the AIA and intertidal area. The habitat map is expected to be used in a variety of applications, particularly to help monitor a subset of ecosystem objectives that will be described in the forthcoming Musquash MPA and AIA monitoring plan.

RÉSUMÉ

Greenlaw, M.E., Schumacher, M.N., McCurdy, Q.M. 2014. A Habitat map and updated mean high water boundary of the Musquash Estuary. Can. Tech. Rep. Fish. Aquat. Sci. 3093: iv + 26p.

Le présent document décrit la création d'une carte des habitats de l'estuaire Musquash, y compris la superficie totale et l'emplacement de chacun des neuf types d'habitat distincts dans l'estuaire. Dans le cadre de ce projet, nous avons aussi délimité, en fonction des marées, la limite moyenne de la marée haute dans la zone intertidale administrée par Pêches et Océans Canada et la zone intertidale. À partir des données par détection et télémétrie par ondes lumineuses (LIDAR), une moyenne précise du niveau de la marée haute a été établie afin d'améliorer la mesure des types d'habitat dans la zone intertidale administrée par Pêches et Océans Canada et la zone intertidale. La carte des habitats devrait être utilisée pour diverses applications, notamment pour aider à surveiller un sous-ensemble d'objectifs écosystémiques qui seront décrits dans le prochain plan de surveillance de la zone de protection marine de l'estuaire Musquash et de la zone intertidale administrée par Pêches et Océans Canada.

1.0 INTRODUCTION

Musquash is a large estuarine embayment with a relatively narrow entrance between rocky exposed headlands. Beaches and intertidal mud/sand flats are found within the harbour, turning to mud in the protected embayments (Hunter and Associates 1982). For a comprehensive ecological overview of the estuary, refer to Singh *et al.* (2000).

On December 14, 2006, the lands and water in the Musquash Estuary up to mean low water were designated a Marine Protected Area (MPA; Figure 1) through regulations pursuant to Canada's *Oceans Act*. An MPA is a coastal or marine area given special status to conserve and protect its natural habitat and marine life. The *Oceans Act*, however, does not apply to the lands and waters between mean low and mean high water levels, and, as a result, the Musquash Estuary MPA Regulations do not apply to the intertidal area administered by Fisheries and Oceans Canada (DFO). Much of this area, referred to as the Administered Intertidal Area (AIA; Figure 1), was transferred from the province of New Brunswick to DFO and is managed, as part of the MPA, pursuant to the *Fisheries Act*, *Federal Real Property and Federal Immovables Act*, and other applicable legislation (e.g., *New Brunswick Trespass Act*, etc.). For a description of the MPA Regulations, AIA boundaries and management priorities for Musquash Estuary refer to DFO (2008).

The Musquash Estuary MPA is divided into three management zones: Zones 1, 2 (a and b) and 3 (Figure 1). As mentioned above, the AIA is also managed by DFO. The level of conservation and protection in each management zone depends on the ecological sensitivity of the zone and the ability to accommodate human activities (DFO, 2008). The upper salt marsh area is not managed by DFO, and was purposely kept out of AIA, given that this area was not entirely provincial land that could be transferred to DFO (D. Fenton, pers. comm). This area is labeled the 'intertidal area' (Figure 1).

Various references have identified the need to create a map of habitat types in the Musquash Estuary MPA and AIA (Singh and Buzeta 2007; Davies *et al.* 2008; Bennett 2013). This document describes the creation of such a map for the Musquash Estuary, including the calculation of the total area of each habitat type in the MPA, AIA and intertidal area. Singh and Buzeta (2007) listed eight ecotypes found within the Musquash Estuary MPA and AIA, described in detail in Singh *et al.* (2000), which form the basis for the mapped habitat types. The habitat types will be useful in helping to monitor a subset of ecosystem objectives within the MPA and AIA (DFO 2011; see Table 1).

The document also describes the process to provide a new tidally based high water boundary for the Musquash Estuary. This may provide advice for potential future boundary reviews of the Ordinary High Water Mark (OHWM) of the AIA, but should in no way be construed as an update to the current legal description of the AIA boundary. The boundary could also provide advice for accurate delineation of the 'intertidal area' (upper marsh area) not managed by DFO, and with no legal boundary.

The need for an updated high water boundary was identified through the effort of creating the habitat map for the Musquash Estuary. The graphical representation of the boundary of the AIA (a graphical representation of the OHWM, with a few artificial lines[1]) had been delineated in advance of LiDAR data collection. The boundary, in some areas, covers roads and forests, and does not extend fully to cover sand and gravel beaches within the Musquash Estuary. With the availability of LiDAR data, a precise tidally-based approximation of OHWM could be delineated to improve the measurement of habitat types within the AIA and intertidal area. A map of the new high water boundary is presented, which was used to calculate the total area of each habitat type within the Musquash Estuary. An ArcGIS shapefile of the new high water boundary is also provided separately and can be accessed by contacting Ocean and Coastal Management division.

2.0 DELINEATING THE MUSQUASH AIA AND INTERTIDAL BOUNDARY

A graphical representation of the OHWM of Musquash Estuary was delineated in 2007, using unknown data sources[1], to complete a Reference Plan of Musquash Estuary (NRCan 2007). This became the graphical representation of the boundary of the AIA (along with a few artificial lines) presented on the current map of the MPA, AIA and intertidal area (Figure 1). The boundary of the 'intertidal area' not managed by DFO (the upper marsh area) was drawn later, also using unknown sources. Given both of these boundaries were created using unknown data sources, and clearly extend to cover habitat beyond the OHWM (covering roads and forest in locations), an updated boundary was necessary, to accurately calculate the area of each habitat type within Musquash Estuary. Beyond the accuracy of the graphical representation of the OMHW boundary, if an accurate OHWM boundary were available, OMHW does not have a precise statistical/mathematical definition. Generally, OHWM boundaries are derived using vegetation and soil changes[2], which may be strongly influenced by recent events, like storms and wave environments, and vary depending on when they are evaluated. Thus, a coastal area exposed to a long fetch, and storm waves, will present a different anecdotal OMHW height, based on these physical markers, than, for example, a nearby area in a protected cove (P. MacAulay, pers. comm.). This presents an issue; that the boundary may vary each time it is surveyed, thus artificially increasing or decreasing the area of each habitat type. Tidally based boundaries are also subject to change, however less frequently. Therefore a tidally based boundary was chosen, using survey-based LiDAR data. Survey-based LiDAR data provide an accurate representation of the vertical height (up to 30 cm vertical accuracy on hard open flat

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[1] The source of the boundary is unknown but was likely drawn using either the Grand Map Index or National Topographic System Maps (J. Grondin, pers. comm.) for the Reference Plan of Musqaush Estuary (NRCan 2007). The line that is presented on the map is merely a graphical representation of the OHWM and this line cannot be used to make any administrative or land management decisions. To create an accurate representation of the OHWM of the Musquash Estuary a licensed land survyor would be hired to produce a legal survey plan. The boundary would be created according to standards in the Association of New Brunswick Land Surveyors Standards Manual. This contains the definitions that apply to the practice of Land Surveying under the New Brunswick Land Surveyors Act, 1986.

[2] The Association of New Brunswick Land Surveyors Standards Manual contains the defintions that apply to the practice of Land Surveying under the *New Brunswick Land Surveyors Act, 1986*. The "Ordinary High Water Mark of a body of water is the limit or edge of its bed and in the case of non-tidal waters it may be called 'the bank" or "the limit of the bank". The ordinary high water mark can be defined as being the line of the medium high tide between the spring and neap tides and is usually accepted as the line of vegetation, or where the nature of the vegetation or soil changes".

surfaces), and thus are an optimal data source for mapping vertically referenced terrestrial boundaries.

A boundary based on the tidal level high high water mean tide (HHWMT) or mean high high water (MHHW) is likely the most accurate representation of the Ordinary High Water Mark (OHWM). HHWMT is equivalent to MHHW, which is the average of the Higher High waters of each day over the 19 years (both high waters in a diurnal tidal area for each day are not the same, there is a higher high water and a lower high water; P. MacAulay, pers. comm.).

During the process of creating the habitat map, it became apparent that most of the area originally labeled 'intertidal area' (area in upper salt marsh area not managed by DFO) was above HHWMT (and thus the OMHW mark). The extent of the upper salt marsh was closer to high high water large tide (HHWLT is the average of the largest high water from each of the 19 years). Therefore, a HHWLT boundary was also delineated to establish a tidally-based high water boundary for the 'intertidal area'. Both of the boundaries were delineated using ArcGIS, with LiDAR-based HHWLT and HHWMT boundaries as guidelines. The final product is a shapefile combining the MPA boundary with the updated high water boundaries of the AIA and intertidal area.

The HHWLT and HHWMT boundaries were defined using LiDAR data. LiDAR (Light Detection and Ranging) is a remote sensing technique that uses a pulsed laser to measure ranges (distances) to earth. There are two types of LiDAR, topographic and bathymetric. Topographic LiDAR uses near-infrared light to map land, while bathymetric LiDAR uses water-penetrating green light to measure the seafloor. Topographic LiDAR data were collected in October, 2006 and again in April, 2007 by AGRG, under contract of the Geological Survey of Canada and Natural Resources Canada. AGRG conducted two aerial LiDAR surveys over the Musquash Estuary (AGRG, 2008). These data were used to produce a LiDAR-based digital elevation model (DEM) and Digital Surface Model (DSM) - precise, three-dimensional surfaces of the terrain - covering the area at a horizontal resolution of 2 metres. A DEM is a surface without objects such as trees and buildings; a DSM is a surface with objects. The DEM was used for boundary delineation (Figure 2).

The original LiDAR data collected were vertically referenced to ellipsoid height. Using GPS-H (http://webapp.geod.nrcan.gc.ca/geod/tools-outils/gpsh.php) it was determined that AGRG had converted the data to the vertical datum CGVD28, which is a good estimation of mean water level (MWL) in this area (± 0.1 m). With the LiDAR referenced approximately to MWL, HHWLT and HHWMT were calculated as the difference between MWL and HHWLT or HHWMT using tidal station tables available from CHS (Table 2). These water levels were used as guidelines for the manual delineation (using ArcGIS 10.1) of the updated high water boundaries.

The final high water boundary of Musquash Estuary is presented in Figure 3. Expansions and contractions from the current depiction of the AIA boundary are presented in Figure 4. The area (km^2) of the AIA, with a tidally-based boundary, stays consistent with the old area as some areas expanded and some contracted (+ 2 m: Table 3, Figure 4).

3.0 MAPPING HABITAT TYPES

Mapping habitat types (Figures 5, 6 & 7) in the Musquash Estuary involved the compilation of geospatial data from a variety of sources. These data included aerial photographs, a LiDAR-based DEM described above, a multibeam sonar survey and CHS hydrographic charts.

Three additional habitat types were mapped during this process (one in the MPA and two in the intertidal area not administered by DFO), giving nine habitat types, which were mapped within the Musquash Estuary (which includes the MPA, AIA and intertidal area). Two of the 'ecotypes'

originally described by Singh *et al.* (2000) could not be mapped (tidal pools and subtidal hard substrate). Data available were too coarse to map tidal pools, and, without validation samples hard substrate could not be distinguished from mixed substrate. It is, however, likely that there are small patches of hard substrate within the subtidal mixed substrate category.

Source Data

DFO Aerial Photographs

In 2007, the DFO hired a private contractor to take aerial images of the entire Musquash Estuary (Figure 8; Bergquist 2007). The results of this survey produced a total of 60 colour aerial photographs, at a scale of 1:10,000 and a pixel resolution of 0.3 metres. The horizontal accuracy of the air photos is listed at +/- 15m. The aerial photographs had been mosaicked prior to receiving them, and are available as a continuous orthophoto of the Musquash estuary and surrounding area. This product was useful for the discrimination of terrestrial and intertidal features, including salt marsh, salt marsh pannes, rocky intertidal areas, impoundment habitats, intertidal flats and sand and gravel beaches.

Multibeam Sonar Survey

A multibeam survey of the Musquash Estuary (Figure 9) was conducted in 2001 by a team including members from the University of New Brunswick and the DFO (Bryne *et al.* 2002). Full coverage of the main subtidal area was obtained using multibeam with additional areas (such as intertidal) being surveyed using sidescan sonar. Multibeam data showed two main distinctions in sediment type. The darker regions, where less acoustic energy is reflected back to the transducer by the seabed, are interpreted as being fine-grained (sand and mud) sediments (low backscatter). The lighter regions, higher backscatter, are interpreted as being coarse sand, gravel and bedrock (Bryne *et al.* 2002, Hughes Clarke *et al.* 2003). The interior of the harbour is homogenously low backscatter while there is a clear indication of a change in sediment type, to mixed sediment at the entrance to the harbour. Sidescan sonar images could not be obtained during the period of this project.

Canadian Hydrographic Service (CHS) Charts

CHS charts were used to provide information in the absence of finer scale multibeam and LiDAR coverage. Chart # 4116 was used (CHS, 2007). This map provided information on bathymetry, substrate and obstacles in near-shore environments. Substrate sample locations from CHS maps (Figure 2) were digitized by the Nova Scotia Geomatics Centre (NSGC) and used to help determine the limit of substrate types, along with the multibeam backscatter and aerial photographs. Although the nautical chart substrate samples are historical and spatially separated, they represent the finest scale detail available for the intertidal/subtidal boundary. This "coastal fringe" area is notoriously difficult to sample and only bathymetric LiDAR with validation substrate samples would be able to fill in the gaps.

Habitat Types

The original '*ecotypes*' described in Singh *et al.* (2000) included: rocky intertidal substrate, tidal pools, sand and gravel intertidal beaches, mudflats, salt marsh, pannes within salt marsh, subtidal soft substrate, and subtidal hard substrate (Singh *et al.* (2000) did not map the habitats, and only provided a description of them).

Although Singh *et al.* (2000) uses the term '*ecotypes*', the term '*habitat type*' is used herein to imply a specific scale (macroscale: 10s ms to 100s km). '*Habitat type*' is preferred over the term '*biotope*', which require biological community data for their description. A '*habitat type*' is the area or environment where an organism normally lives or occurs, which would also normally require biological species data to establish. However, in this report the term '*habitat type*' is used to imply physical habitat only, save salt marsh habit types, which include biological data but are easily distinguishable using the techniques available. Even though we are lacking a nationally recognized standardized habitat classification scheme, the terms '*habitat type*' and '*biotope*' are in accord with hierarchical ecological classification schemes used in the Pacific and Maritimes Regions (DFO 2012; Greenlaw Unpublished), while '*ecotype*' is not.

In addition to the '*ecotypes*' described in Singh *et al. (2000),* three habitat types including subtidal mixed substrate, impoundment salt marsh and impoundment tidal pool were added during the creation of the habitat map. Subtidal mixed substrate was identified from examination of multibeam data that were only available after the original '*ecotypes*' from Singh *et al.* (2000) had been described. Subtidal mixed substrate was present only in MPA Zone 1.

The mudflat '*ecotype*' was revised to 'intertidal flat', to acknowledge that the composition of the flats may be mud or sand. Subtidal hard substrate was not delineated, as no substantial amount could be differentiated from the mixed-substrate category using the available data sources.

The impoundment salt marsh and impoundment tidal pool habitat types were added to the 'intertidal area' that is not managed by DFO. The impoundment salt marsh and impoundment pools identified within the Musquash Estuary are part of impoundments originally established by Ducks Unlimited - the impoundments that were included within the original 'intertidal area' delineation are now breached and gradually returning to intertidal areas (R. Singh, pers. comm.).

Habitat Type Descriptions

Exposed Coastline - Rocky exposed coastline at the headlands of Musquash Estuary or external to the inlet. The wave-exposed headlands are composed of purplish-red sandstones with minor conglomerates and shales (Singh *et al.* 2000).

Impoundment Salt Marsh - The 'impoundment salt marsh' is within three dyked impoundments originally established by Ducks Unlimited to create freshwater pond and marsh habitat for ducks. Those impoundments that were included within the original 'intertidal area' delineation are now breached and gradually returning to intertidal areas (R. Singh, pers. comm.). These were still included as impoundment habitat in the habitat classification, but in the future may need to be changed to salt marsh habitat.

Impoundment Salt Marsh Pools - The 'impoundment pools' are within dyked impoundments originally established by Ducks Unlimited to create freshwater pond and marsh habitat for ducks. Those impoundments that were included within the original 'intertidal area' delineation are now breached and gradually returning to intertidal areas (R. Singh, pers. comm.). These were still included as impoundment habitat in the habitat classification, but in the future may need to be changed to salt marsh panne and pool habitat.

Intertidal Flat - Sparsely vegetated intertidal sand and mud-flats are exposed at low tides. They occur between salt marsh communities landward and up river, and subtidal areas seaward. There is little vascular plant growth, but it is expected that algae, worms, clams, snails and crabs will be common. The flats form depositional environment protected from high-energy wave action. The substrate is exposed completely during low spring tides, and ranges in composition from silt to sand. Tidal creek channels exposed at low tide are included in this community.

Rocky Intertidal – Intertidal areas represented by extensive spatially dominant hard surface (> 80% rock surface) that include bedrock outcrops and boulder lag with occasional deposits of overlaying sediment ranging in size from mud to boulders. Within Musquash Harbour, crystalline limestone and dolomite with quartzite and quartzitic argillite outcrops form the cliffs. Further in, the bedrock is mantled with a shallow veneer of glacial drift (Singh *et al.* 2000).

Salt Marsh - Wetland that is flooded and drained by tidal salt water. The soil is expected to be composed of deep mud or peat. The peat is made of decomposing plant matter that is often several feet thick. Generally in Fundy marshes, plant communities consist of the genera *Spartina, Puccinellia*, *Distichlis* as well as rushes and reeds (*Juncus*, *Scirpus*), with other scattered perennials. Musquash is dominated by *Spartina alterniflora*. Species found most frequently in the raised banks include *Spartina patens, triglochin maritime, Plantago maritime, Atriplex padula, Suaeda maritime, Limonium nashii and Salicornia europaea*. More species information about Musquash Salt Marsh can be found in Singh *et al.* (2000).

Sand and Gravel Intertidal Beach - Intertidal beach with the bulk of sediment containing a high percentage of sand, or a mixture of predominantly sand and gravel, with the possibility of some mud (< 20%).

Subtidal Mixed Substrate – Will likely contain a variety of sediment sizes, from muds, sands to gravel, all mixed together; geologically known as a diamicton, or in glaciated terrains is more commonly known as glacial till.

Subtidal Soft Substrate - The subtidal soft substrate category includes sediments that range in size from clay to sand. These particles can be readily moved by tidal currents, but once deposited they can become consolidates, sometimes with the aid of organisms such as mats of microalgae and biofilm (Schoellhamer *et al.* 2007). The composition may be shifted from an overall increase or decrease in sediment supply from upstream, and sea level rise.

Salt Marsh Pannes and Pools - Wet depressions embedded within the salt marsh. They are isolated from tidal creeks. Pools are deeper and tend to retain water through the summer, whereas pannes do not. Species richness and composition depend on a variety of factors, including salinity, water levels, and substrate type. Salinity levels, generally, can be up to three times that of ocean water.

Creation of Musquash Habitat Map

Each habitat type was manually delineated, using the data sources as guides, as a vector-based polygon using the projected coordinate system of WGS 84 UTM Zone 19N and a scale of approximately 1:10,000.

The habitat types in the intertidal area of Musquash Estuary (not managed by DFO) were delineated using aerial photographs and terrestrial LiDAR data. Aerial photographs clearly distinguished between the salt marsh, salt marsh pannes and pools, rocky intertidal, impoundment salt marsh and impoundment pools. LIDAR data were used to determine areas with an absence of salt marsh (channel features) categorized as intertidal flats.

The habitat types in the AIA were delineated using aerial photographs, multibeam, CHS substrate samples and CHS charts. Aerial photographs were used to determine the extent of the rocky intertidal zone. The extent of the intertidal flats were mapped using CHS maps, aerial photographs and CHS substrate characterizations (on CHS charts), as there was an absence of detailed intertidal substrate information. Occasionally intertidal habitat types extended into the MPA, and thus there are small portions of intertidal flat, rocky intertidal and salt marsh within the MPA. This is due to the different data products used to delineate the original lowest normal tide MPA boundary and habitat types.

The subtidal habitat types were mapped using the multibeam, sidescan sonar and CHS charts. Subtidal mixed substrate was identified from examination of multibeam data that were only available after the original '*ecotypes*' from Singh *et al.* (2000) had been defined. The subtidal mixed substrate was delineated based on the limits of a more complex habitat pattern visible in the multibeam DEM. The interior seabed of the harbour is homogenously low backscatter while there is a clear indication of a change in sediment type, to mixed substrate, just at the entrance to the harbour. Subtidal mixed substrate is defined as containing a variety of sediment sizes, including muds, sands, and gravels, all mixed together[3]. The subtidal soft sediment boundary was approximately delineated using the CHS Lowest Normal Tide (LNT) boundary, and multibeam that exhibited a smooth pattern. Once all of the habitat types were mapped (Figures 5, 6 & 7), the total area in the intertidal area, AIA and MPA were calculated (Tables 4 & 5).

5.0. DISCUSSION

A habitat map (Figures 5, 6 & 7) and updated high water boundary (Figures 3) of the Musquash Estuary are provided. These provide a necessary component to help monitor ecosystem objectives set out in the MPA monitoring plan (DFO 2011), and may provide advice for potential future boundary updates to the AIA and intertidal area. To advance the Musquash Estuary monitoring plan the total area and location of each habitat type or '*ecotype*' within the estuary are now provided. Going forward, this will provide an adequate baseline to determine the proportion and frequency that '*ecotypes*' are disturbed or lost. To quantify disturbance or loss of '*ecotype*' area the full classification should be updated periodically using the variety of techniques used to originally survey the Musquash Estuary. Over time, the composition of salt marsh, intertidal flats, and subtidal soft substrate may be shifted from an overall increase or decrease in sediment supply from upstream, and sea level rise. The backshore limit of beaches may also be influenced by strong storm events or sea level rise. The classification should be updated more frequently if, during routine monitoring, disturbance or loss of an 'ecotype' is observed to be beyond the expected annual variation.

To improve the current classification of habitat types a variety of validation techniques could be used. The most apparent would be to incorporate substrate samples that have already been taken and are awaiting analysis. These samples were taken in the intertidal and subtidal soft substrate portions of the classification and would help determine the transition from sandy sediment to muddy sediment, which contain different (although related) community types.

High definition underwater video is an optimal technique that could be used to validate the subtidal mixed substrate area. This area, due to its complexity and potential underlaying

[3] Schumacher, M., Greenlaw, M.E., King, E., Doon, M., Page, F. and Kostylev. A knowledge-based approach for the determination of surficial substrate using surficial geology and geomorphology in the coastal western Maritimes Region. Can. Tech. Rep. Fish. Aquat. Sci.: iv + 35 p. Unpublished Report.

bedrock, would not be possible to sample with grabs or cores. Underwater video would provide validation samples to distinguish areas that are truly mixed substrate from areas that may be bedrock or boulder. They would also determine the mixed substrate composition, and biological community types present in this substrate type.

Tidal pools could not be identified at the scale that the aerial photographs were taken. Aerial photographs could be taken at a lower altitude along the coastline to distinguish finer scale beaches and tidal pools, possibly with a planned test flight of a drone proposed by Fisheries Protection (S. Corrigan. pers. comm).

Simplistic methods could be used to determine the amount of freshwater or salt water in the impoundments that are breached and returning to regular salt marsh habitat, including sending personnel there, or focusing personnel for a short period during the annual Musquash Paddle.

Finally, bathymetric LiDAR would be an optimal technique to fill in the gaps between the subtidal multibeam and terrestrial LiDAR, where CHS maps were used to distinguish subtidal boundary of LNT. Bathymetric LiDAR uses water-penetrating green light to measure the seafloor, in contrast to terrestrial LiDAR, which uses near-infrared light to map land. Bathymetric LiDAR typically penetrates around 2-3 times the secchi depth, which in Musquash is expected to be only around 1-2 m. However, Musquash is a very shallow estuary, with a maximum depth of 15 m. Bathymetric LiDAR would likely cover a large portion (if not all) of the gap between the terrestrial LiDAR and the multibeam coverage. LiDAR primarily delivers a DEM, but can also deliver signal intensity. Signal intensity, coupled with validation samples, would provide an accurate means to determine the transition between areas of distinctive soft substrate grain sizes, and thus community types.

Also, going forward, the habitat classification could be further developed to delineate '*biotopes*', with the incorporation of biological sampling data. A '*biotope*', in contrast to a '*habitat type*', is an area that is uniform in environmental conditions and its distribution of animal and plant life. Surveys of communities within each ecotype would have to be undertaken through standardized per area sampling such as transect or quadrats, grabs, or underwater video.

Table 1. Conservation objectives, proposed indicators and monitoring strategies (DFO 2011) for the Musquash Estuary MPA and AIA, relevant to the creation of a map of habitat types (ecotypes).

Conservation Objectives	Indicator	Monitoring Strategy
Productivity: so that each component (primary, community, population) can play its role in the functioning of the ecosystem by maintaining abundance and health of harvested species	Total biomass and spatial distribution of species in each trophic level within each ecotype (P1)	Survey of species within each ecotype through standardized per area sampling such as transect or quadrats
Biodiversity: by maintaining the diversity of individual species, communities, and populations within the different ecotypes	Number of species in each trophic level within each ecotype, and the abundance of keystone and/or dominant species (B1)	Survey of species within each ecotype through standardized per area sampling such as transect or quadrats (visual surveys where applicable)
	Number of exotic species within each ecotype, relative to exotic species in region (B2)	Survey of exotic species within each ecotype, and estimate of exotic species in region through standardized per area sampling such as transect or quadrats (visual surveys where applicable)
	Number of species at risk within each ecotype (B3)	Survey of species within each ecotype through standardized per area sampling such as transect or quadrats (visual surveys where applicable)
Habitat: in order to safeguard the physical and chemical properties of the ecosystem by maintaining water and sediment quality	Total area and location of each ecotype within the estuary, and the proportion and frequency that it is disturbed or lost (H1)	Map area distribution of each ecotype within the estuary using aerial photographs and GIS software

Table 2. The tidal station in proximity to Musquash Estuary MPA and AIA. Values represent the conversion from lowest normal tide to each tide level in *metres*: high high water large tide (HHWLT), high high water mean tide (HHWMT), and mean water level (MWL). In brackets are the differences between MWL and HHWLT or HHWMT.

Tidal Station	HHW Large Tide	HHW Mean Tide	Mean Water Level
Five Fathom Hole	8.5 (4.2)	7.43 (3.13)	4.3

Table 3. Area (km^2) of the old AIA and AIA with the updated mean high water (MHW) boundaries high high water large tide (HHWLT) and high high water mean tide (HHWMT).

	Updated Boundary	Current Boundary
AIA area (km^2)	4.092	4.094

Table 4. Area (km^2) of each ecotype found in each of the Musquash MPA, AIA.

Habitat Type	MPA	AIA	Intertidal Area	Grand Total
Exposed Coastline	0.00	0.03	0.00	0.03
Impoundment Salt Marsh	0.00	0.00	0.51	0.51
Impoundment Salt Marsh Pool	0.00	0.00	0.27	0.27
Intertidal Flat	0.81	2.78	0.63	4.21
Rocky Intertidal	0.11	0.89	0.09	1.09
Salt Marsh	0.07	0.02	4.02	4.12
Salt Marsh Panne and Pool	0.00	0.00	0.31	0.31
Sand and Gravel Intertidal Beach	0.00	0.09	0.00	0.09
Subtidal Mixed Substrate	0.12	0.00	0.00	0.12
Subtidal Soft Substrate	6.30	0.28	0.00	6.59
Grand Total	7.42	4.09	5.83	17.35

Table 5. Percent coverage (%) of each habitat type found in each of the Musquash MPA, AIA and intertidal area for the HHWLT delineation.

Habitat Type	MPA	AIA	Intertidal Area	Grand Total
Exposed Coastline	0.00%	0.16%	0.00%	0.16%
Impoundment Salt Marsh	0.01%	0.00%	2.94%	2.95%
Impoundment Salt Marsh Pool	0.00%	0.00%	1.54%	1.54%
Intertidal Falt	4.69%	16.00%	3.61%	24.30%
Rocky Intertidal	0.62%	5.15%	0.50%	6.26%
Salt Marsh	0.40%	0.13%	23.19%	23.73%
Salt Marsh Panne and Pool	0.00%	0.00%	1.76%	1.76%
Sand and Gravel Intertidal Beach	0.00%	0.54%	0.00%	0.55%
Subtidal Mixed Substrate	0.70%	0.00%	0.00%	0.70%
Subtidal Soft Substrate	36.34%	1.62%	0.00%	37.96%
Grand Total	42.76%	23.60%	33.63%	100.00%

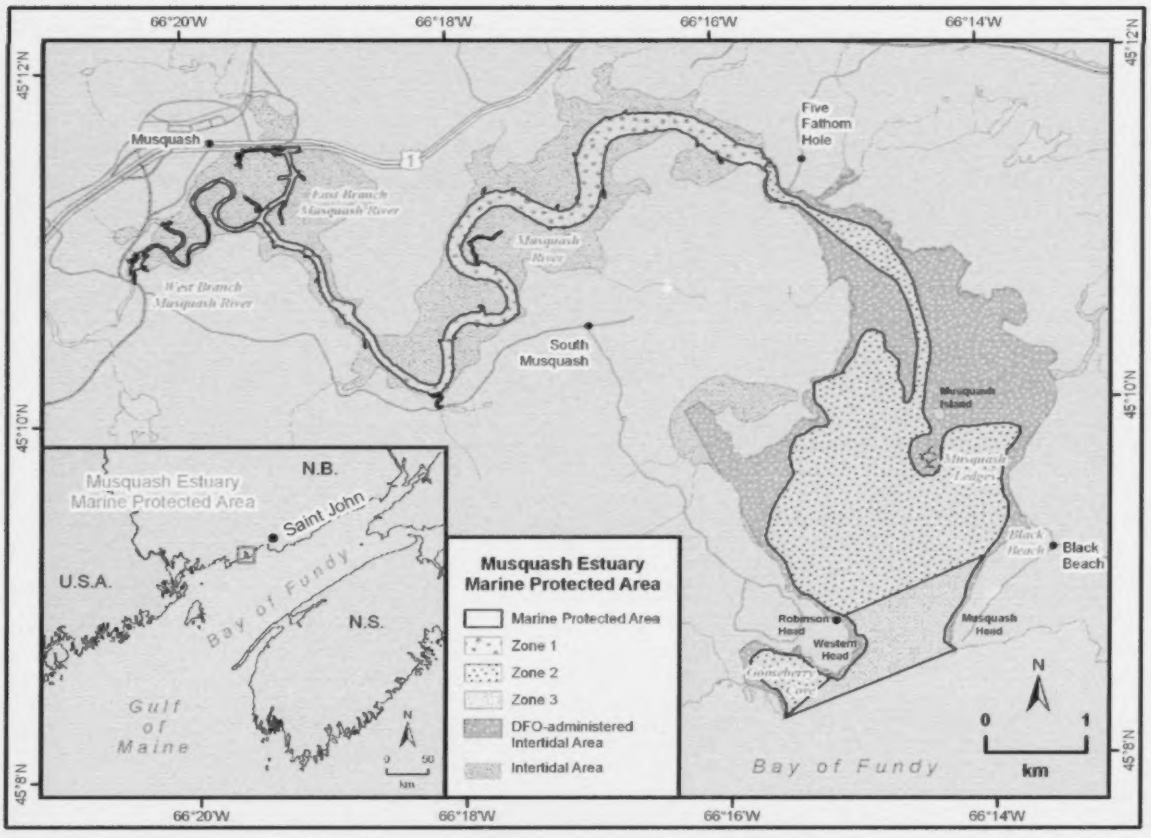

Figure 1. The Musquash Estuary Marine Protected Area (MPA) and Administered Intertidal Area (AIA) managed by Fisheries and Oceans Canada. Figure from the Musquash Management Plan (DFO 2008).

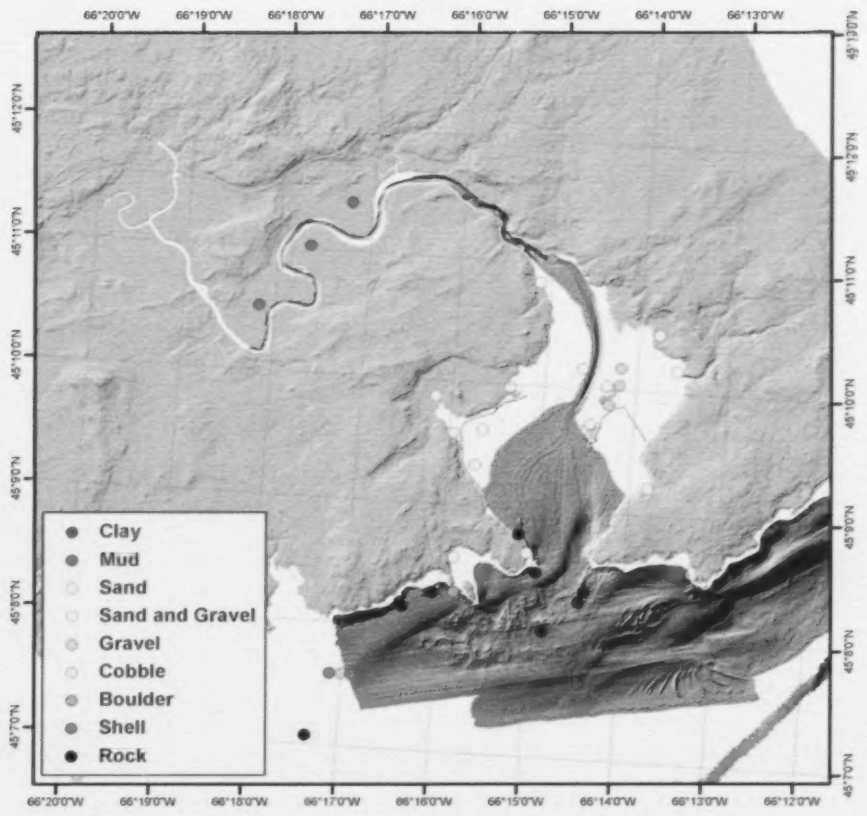

Figure 2. The extent of the LiDAR (green) and multibeam (blue) data, and CHS substrate characterizations present in the Musquash Estuary and surrounding areas.

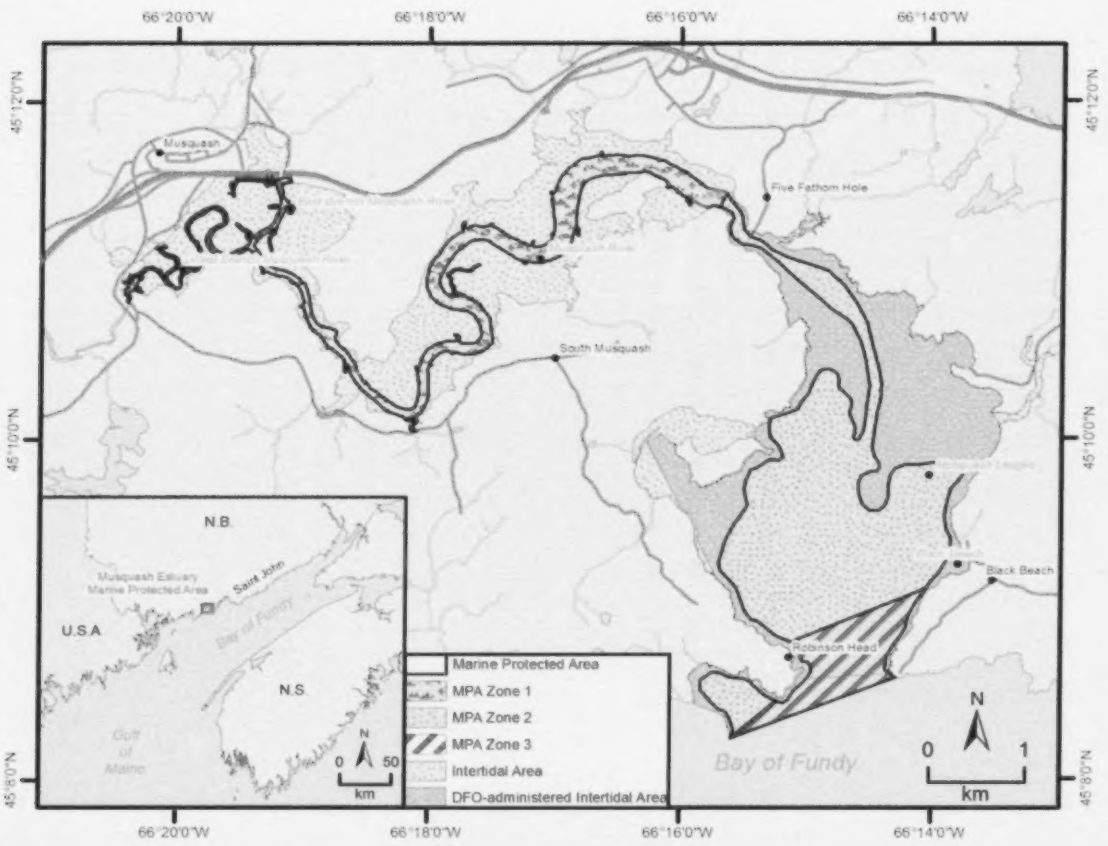

Figure 3. The boundary of the Musquash Estuary MPA and updated high water boundary of the Administered Intertidal Area (AIA) at high high water mean tide (HHWMT) and the intertidal area high high water large tide (HHWLT). The MPA and AIA are managed by Fisheries and Oceans Canada (DFO). This will provide advice for potential future boundary changes to the AIA and intertidal area. This is not to be interpreted or used as an update to the current legal descriptions of the MPA and AIA.

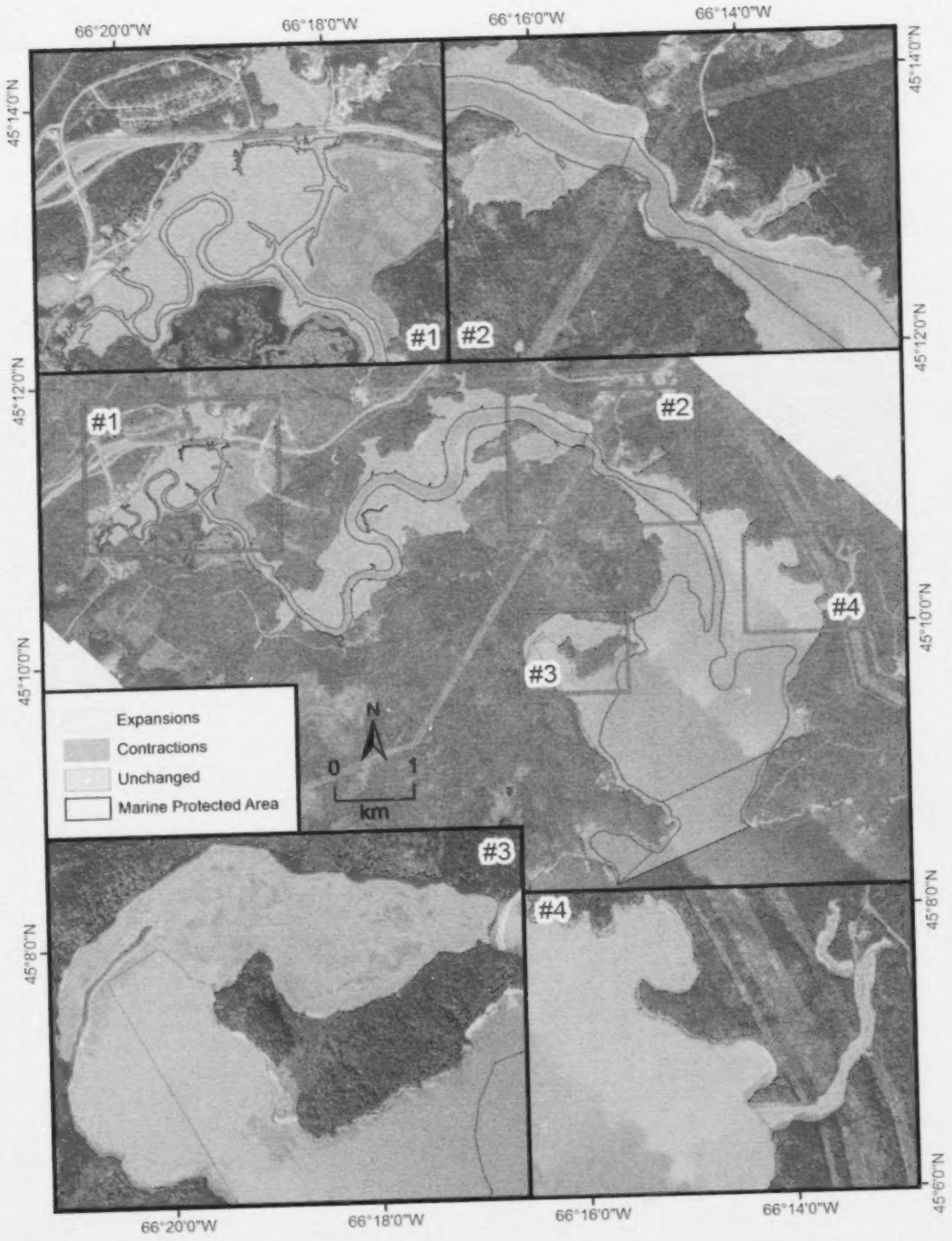

Figure 4. Expansions and contractions of the AIA (presented at high high water mean tide) and intertidal area (presented at high high water large tide) boundaries from the current boundary presented in Figure 1. This may provide advice for potential future boundary changes to the AIA and intertidal area. This is not to be interpreted or used as an update to the current legal descriptions of the MPA and AIA.

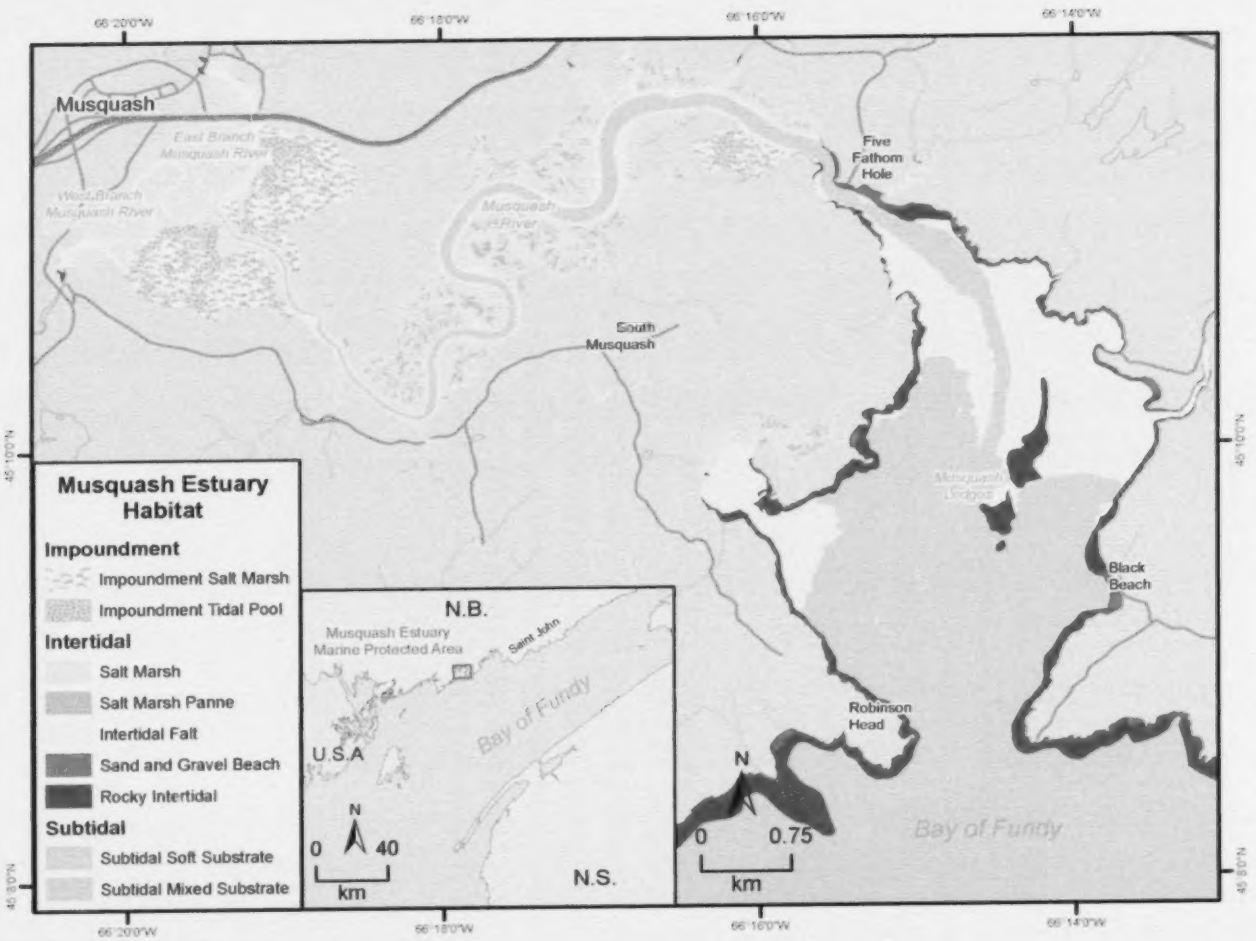

Figure 5. A map of Musquash Estuary showing the spatial distribution of the mapped habitat types.

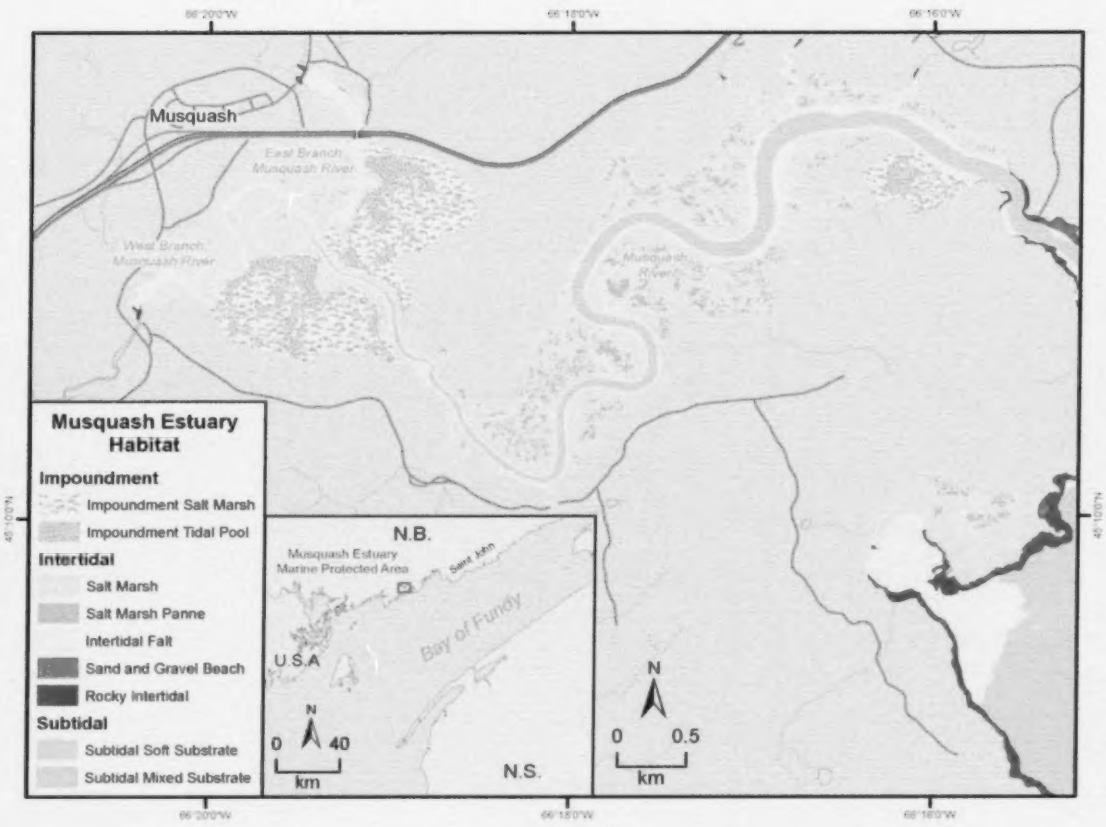

Figure 6. Habitat types in the marsh portion of the Musquash Estuary.

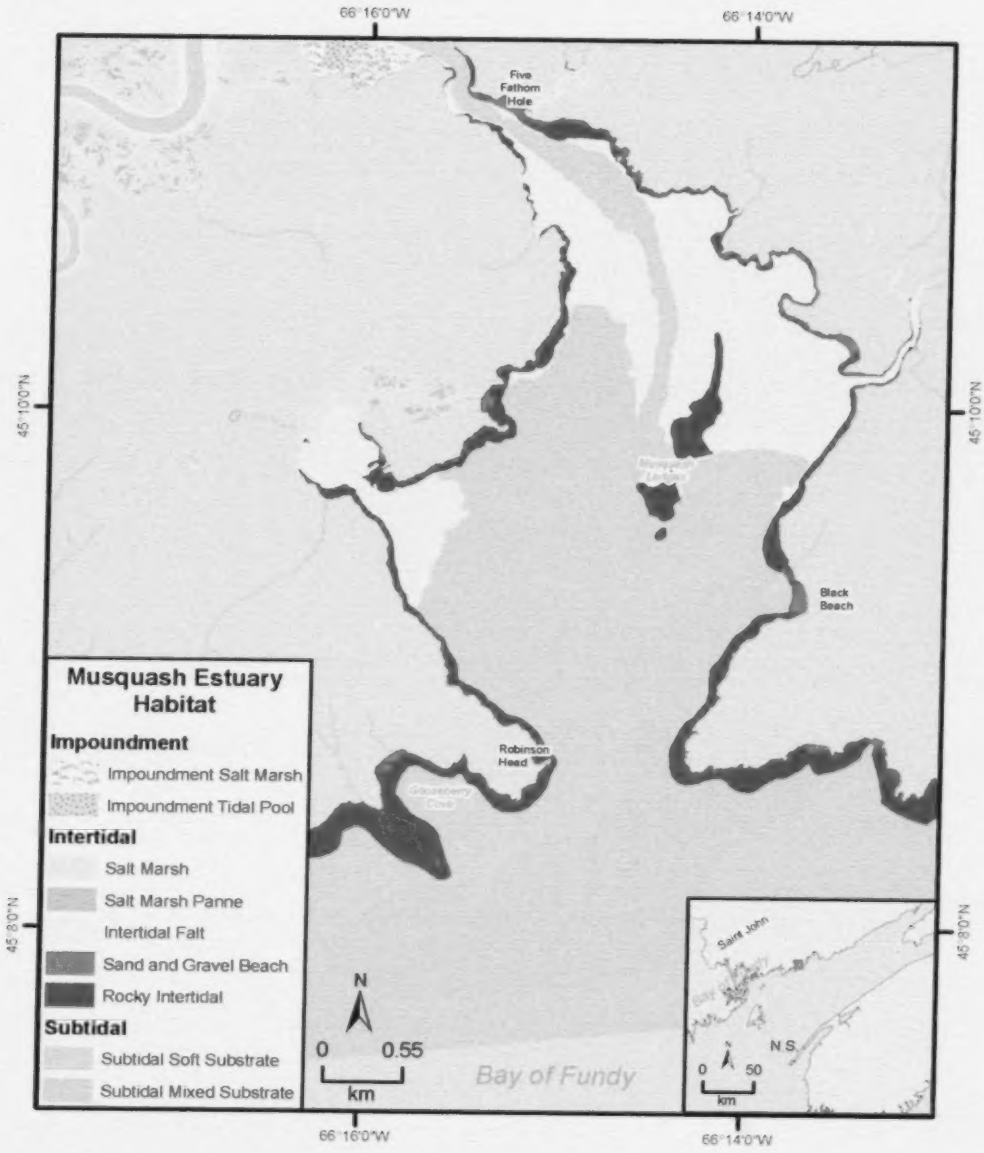

Figure 7. Habitat types in the harbour portion of the Musquash Estuary.

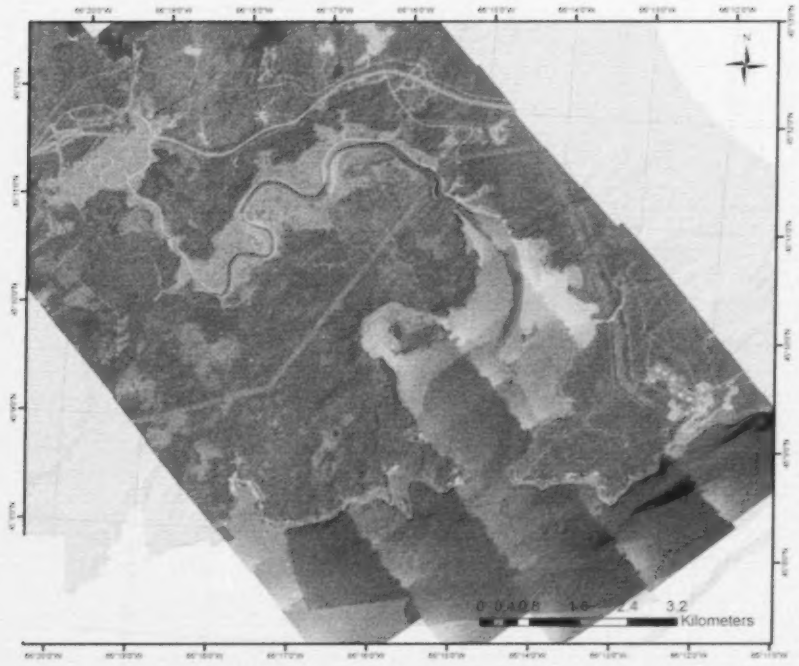

Figure 8. Orthophoto mosaic (2007) present in the Musqush Estuary.

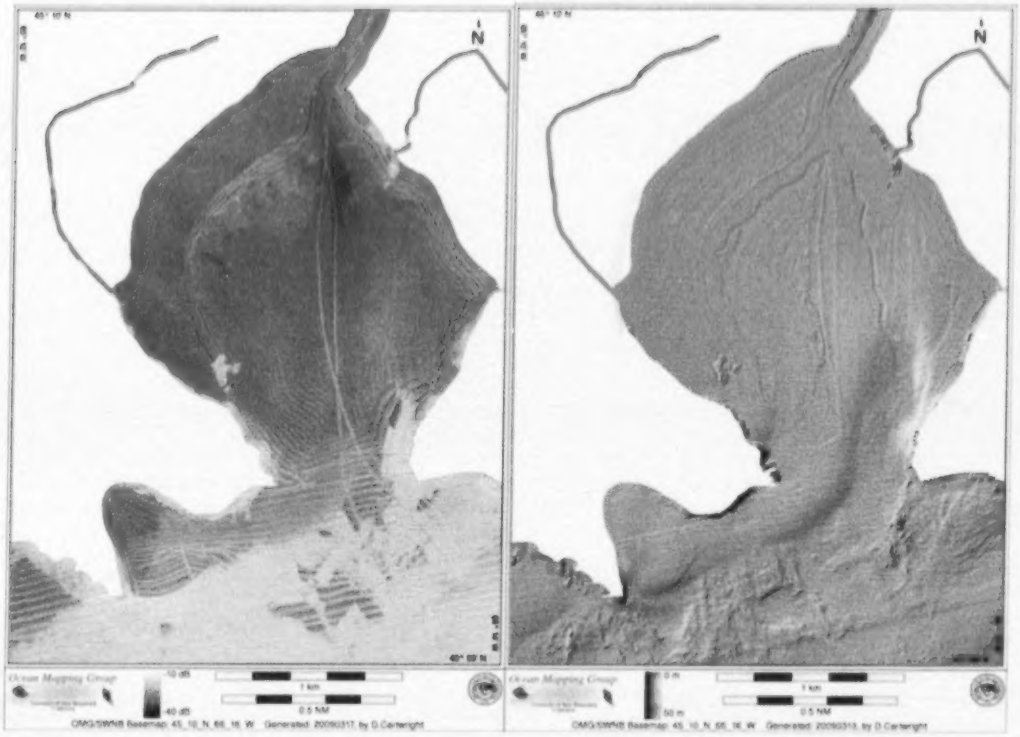

Figure 9. The extent of the multibeam backscatter (left) and the multibeam digital elevation model (right) in the Musquash Estuary and surrounding area. The more complex regions were interpreted as being coarse sand, gravel and bedrock. The multibeam backscatter data also showed that the interior harbour is homogenously low backscatter while there is a clear indication of a change in sediment to rock at the entrance to the harbour. The darker regions show areas where less acoustic energy is reflected back to the transducer by the seabed and are interpreted as being fine grained (sand and mud) sediments (low backscatter). The lighter regions indicate high backscatter (Bryne *et al.* 2002), interpreted as being coarse sand, gravel and bedrock.

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